Diagnostic Value of Intracardiac Phonocardiography in Some Complicated Cardiac Problems *

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INTRACARDIAC phonocardiography [10, 12, 15, 16] has not only helped to achieve a better understanding of the basic phenomena of cardiovascular sound,[14] but has also offered valuable aid in the diagnosis of congenital and acquired heart disease.[4-6, 9, 11, 12]

Among the technics for recording intracardiac sounds, those described by Lewis *et al.*[12] and by Soulie *et al.*[15] provide precise localization of the source of cardiac sounds and murmurs, and have been of diagnostic value particularly in cases of ventricular septal defect,[5, 12] patent ductus arteriosus,[3-6, 11, 12] pulmonary valvular and infundibular stenosis,[3] rupture of sinus of Valsalva into the right cavities of the heart [6] and Lutembacher's syndrome.[7]

The intracardiac microphone used by Lewis *et al.*[12] is a hollow cylinder of activated barium titanate which is incorporated in the tip of a specially designed catheter. Soulie *et al.*[15] use an intracardiac manometer sealed in the tip of a catheter, which is able to operate as a pressure and sound transducer at the same time. Both these technics have the advantage of easy performance and produce recordings of good quality.

It is the purpose of this paper to present three problem cases in which intracardiac phonocardiography was of great diagnostic help, and to emphasize the practical value of this technic in establishing the diagnosis even when clinical and hemodynamic findings are equivocal.

Methods of Study

The sound catheter described by Lewis *et al.*[12] has been used in this study (Fig. 1). The tip of this catheter consists of a hollow cylinder of activated barium titanate (0.038-inch outer diameter, 0.5-inch long) which is able to convert sonic vibrations into electrical energy. The body of the catheter is a coaxial cable of the same diameter and 5 feet long, to which the barium titanate microphone is soldered. Both the tip and the body are coated with a plastic substance which prevents direct contact of the microphone with blood and inner walls of the heart and vessels (a possible source of artifact) and allows chemical sterilization of the apparatus.

The output of the sound catheter after a preliminary amplification by a specially designed pre-amplifier (Fig. 1) is fed into a two-channel photographic recording apparatus (twin-beam-Sanborn) used for routine chest phonocardiography.

The sound catheter, because of its metallic components, is clearly seen on fluoroscopy. The sound recordings were made after routine right heart catheterization and did not alter the latter procedure, except for the additional time required.

Case 1. B. D., aged 17, had a known heart murmur since the age of six, with mild decrease in exercise tolerance.

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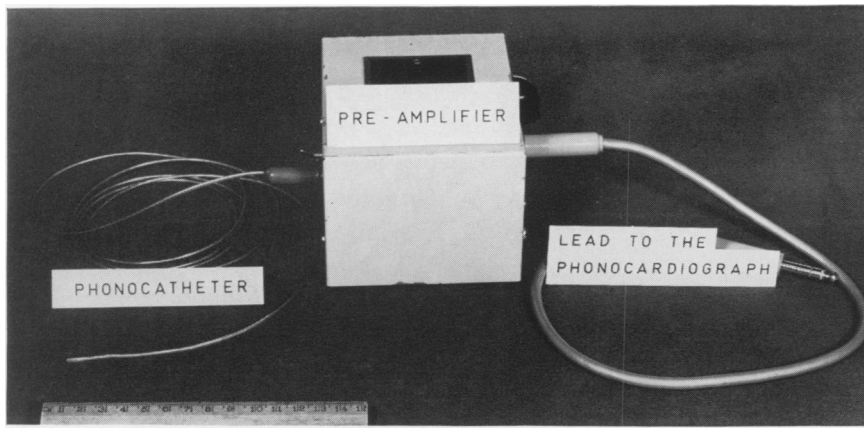

FIG. 1. Assembly for recording intracardiac sounds. (Phonocatheter and pre-amplifier were designed and built by the Naval Air Development Center of Johnsville, Penna.)

On examination she was a normally developed young girl, with no cyanosis or clubbing. The blood pressure was 110/70, the rhythm was regular, there was a diffuse systolic thrill best felt at the base, with a loud, harsh systolic murmur, Grade III (in IV) best heard at the third and fourth left intercostal space. The second sound was split, with a soft pulmonary component. A chest phonocardiogram revealed a pansystolic murmur in the third and fourth interspace and an ejection murmur at the base.

ECG showed normal sinus rhythm with marked right ventricular hypertrophy. On fluoroscopy a small heart, a small pulmonary conus and no increased vascularity of the lungs or pulsation of the hila were noted.

The clinical impression was that of a possible ventricular septal defect with associated pulmonary stenosis. On right heart catheterization a systolic gradient of 105 mm. Hg was demonstrated between the right ventricle and the pulmonary artery. The pressure tracings suggested an infundibular chamber in which the systolic pressure was about 60 mm. Hg. No evidence of shunt in either direction could be demonstrated by oxygen saturation and dye dilution studies.

Selective angiocardiography showed an infundibular type of pulmonary stenosis with a large influndibular chamber.

The intracardiac phonocardiogram (Fig. 2), while showing a loud ejection murmur in the pulmonary artery, revealed a loud pansystolic murmur, typical of ventricular septal defect, within the large infundibular chamber.

Comment: Although the clinical impression was that of a ventricular septal defect with pulmonary stenosis, the latter being the predominant lesion, right heart catheterization, dye dilution studies and selective angiocardiography failed to reveal a ventricular septal defect. The intracardiac phonocardiogram was the only supporting evidence of an interventricular communication, by revealing a pansystolic murmur in the large infundibular chamber.[4, 12] Operation was performed under direct vision with cardiopulmonary bypass, during which a defect of the interventricular septum, about one cm. in diameter, facing the infundibular chamber, was found, in addition to an infundibular pulmonary stenosis.

A pansystolic murmur, localized within the right ventricle (Fig. 3) is the phonocardiographic diagnostic sign of ventricular septal defect. It is present in all cases of ventricular septal defect, with or without pulmonary stenosis or pulmonary hypertension, provided there is left to right shunt.[4, 11] It is present with bidirectional shunt but absent in pure left to right shunt, as in typical Tetralogy of Fallot.[3]

In other problem cases, such as ventricular septal defect with tricuspid incompetence, in which oxygen studies suggested an atrial septal defect rather than a ventricular septal defect, this sign has been most helpful in ascertaining the presence of a defect in the interventricular septum. Conversely, the absence of this murmur was very helpful in excluding an interventricular shunt in cases of low-lying

atrial septal defect, in which oxygen studies suggested a ventricular septal defect rather than an atrial septal defect, or the co-existence of both.

Case 2. B. B., a 19-year-old woman, was known to have a heart murmur from the age of 11 years, without a history of rheumatic fever. The description of the murmur varied from systolic (at age 11), systolic and diastolic (at age 15) and continuous (at age 18). A month prior to admission she had sudden precordial distress with dyspnoea while at work in her home.

On admission to hospital early in 1959 she had malaise, mild fever and a continuous machinery murmur at the third and fourth left interspace, with a wide pulse pressure (blood pressure 130/50). *Streptococcus viridans* was grown from several blood cultures and she was treated for subacute bacterial endocarditis. She responded well and made a complete recovery from the endocarditis. In view of the history and clinical examination the following possibilities were suggested: aortic stenosis and insufficiency, ventricular septal defect with aortic insufficiency, patent ductus arteriosus, rupture of a sinus of Valsalva.

She was investigated further to establish the diagnosis. Right heart catheterization revealed a rise of 3 vols. % oxygen in the right ventricle over the right atrial average, with no further rise in the pulmonary artery. The pressures were normal throughout the right heart chambers and pulmonary artery. Despite these studies, the possibilities of a ventricular septal defect with aortic insufficiency or of a rupture of a sinus of Valsalva into the right ventricle, still existed. Patent ductus seemed unlikely. The intracardiac phonocardiogram (Fig. 3) revealed a pansystolic murmur within the right ventricle and no continuous murmur either in the right ventricle or in the pulmonary artery. This established the diagnosis of a ventricular septal defect and also excluded rupture of a sinus of Valsalva into the right ventricle, in which case there would have been a continuous murmur in that chamber,[9] and patent ductus arteriosus, in which case (Fig. 4) a

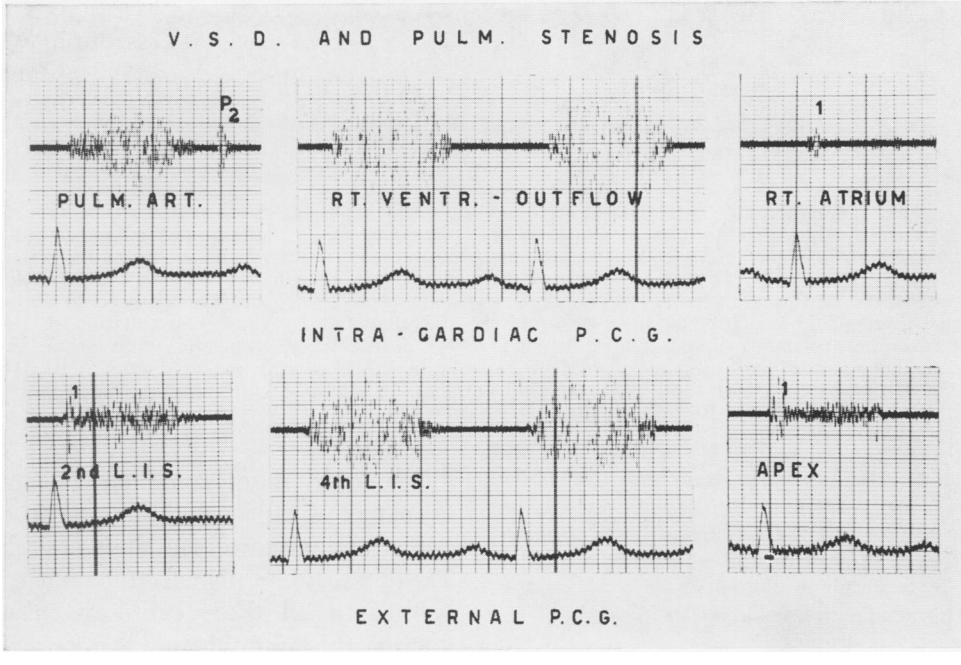

FIG. 2. Intracardiac and external phonocardiograms in a case of ventricular septal defect with pulmonary stenosis. A loud pansystolic murmur localized within the outflow tact of the right ventricle is a diagnostic sign of ventricular septal defect, even when oxygen studies are equivocal as in this case. Note the close similarity between the intra-ventricular murmur recorded by the phonocatheter and that recorded from the 4th left interspace by the external microphone. No murmurs are recorded within the right atrium. Within the pulmonary artery and externally over the 2nd left interspace, a different type of murmur (mid-systolic or diamond shaped) is recorded, due to pulmonary stenosis. The pulmonary valve closure which is very soft in this condition, is recorded, in this case, only by the phonocatheter.

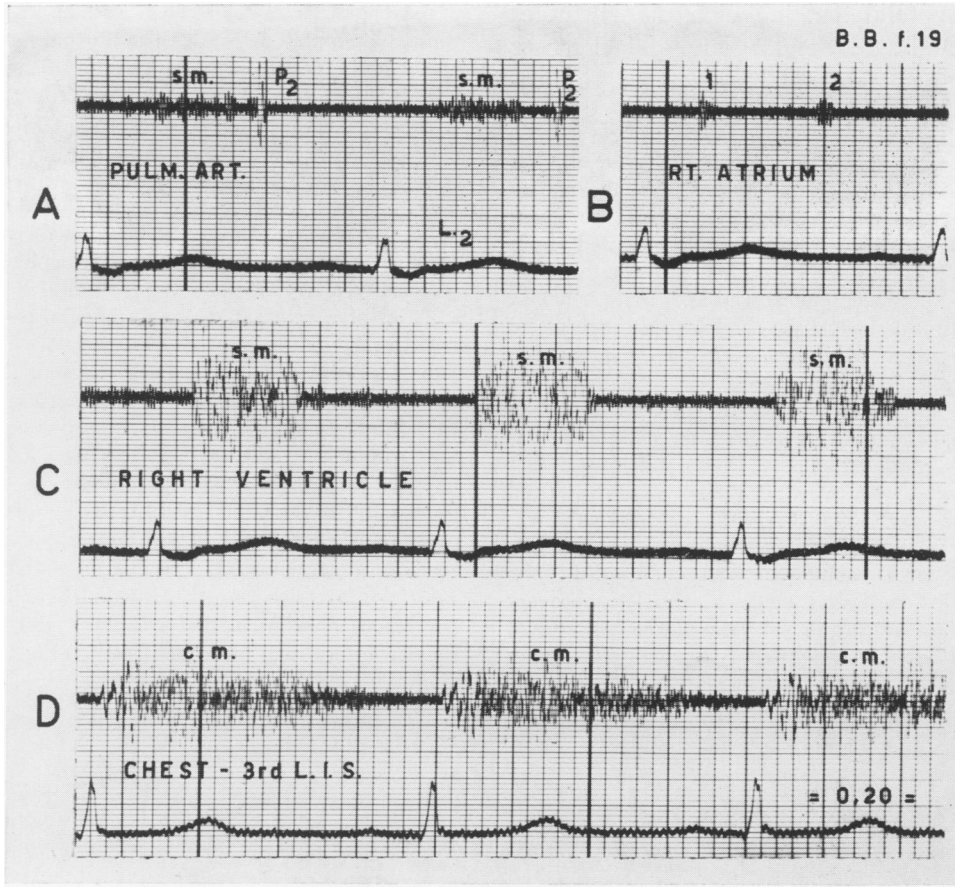

FIG. 3. Ventricular septal defect with aortic insufficiency. A, B, C, intracardiac phonocardiogram showing the typical features of ventricular septal defect: a loud pansystolic murmur in the right ventricle, a flow murmur in the pulmonary artery and no murmurs within the right atrium. D, external phonocardiogram showing a machinery murmur. The systolic component of this murmur is due to the ventricular septal defect and the diastolic to aortic insufficiency. These two components cannot be differentiated by simple auscultation or external chest phonocardiography. Ventricular septal defect when associated with aortic insufficiency is a difficult diagnostic problem and may be mistaken with patent ductus arteriosus, aortic septal defect and rupture of sinus of Valsalva. In all these conditions the intracardiac phonocardiogram is of diagnostic value.

continuous murmur would have been present in the pulmonary artery.[5, 9, 12] Thus it was reasonable to assume that the continuous murmur heard over the chest was due to a ventricular septal defect with aortic insufficiency.

A retrograde aortogram was performed, which confirmed this diagnosis.

Comment: Ventricular septal defect associated with congenital or acquired aortic insufficiency has been recognized as a difficult diagnostic problem.[1, 2, 8, 13] The presence of a continuous murmur, a wide pulse pressure and the evidence of a left to right shunt could be due as well to patent ductus arteriosus, aortic septal defect and rupture of a sinus of Valsalva. The intracardiac phonocardiogram is most helpful in all these cases, as in patent ductus arteriosus, where a continuous murmur is localized within the pulmonary artery, loudest at the bifurcation or in the left branch;[3] in aortic septal defect, where a continuous murmur is recorded within the pulmonary artery, loudest just above the pulmonary valve;[3] in rupture of the

sinus of Valsalva, in which a continuous murmur is localized to that chamber (right atrium or right ventricle) into which the sinus ruptures.[9]

Case 3. J. L., a man aged 57 years, was admitted with the history of two episodes of rheumatic fever in childhood and recognition of a heart murmur at the age of 20.

On admission, examination revealed an irregular pulse, increased jugular venous pressure, a loud apical first sound and a split second sound at the base. There was also an ejection type of murmur loudest over the pulmonary artery and a questionable apical mid-diastolic murmur. The ECG showed atrial fibrillation and incomplete right bundle branch block. On fluoroscopy he had an enlarged pulmonary artery with pulsating hilar vessels. Both right and left atria were slightly increased in size. No calcium was seen in any valve area. Right heart catheterization revealed a left to right shunt at the level of the atria and the catheter crossed an atrial septal defect and entered the left atrium and left ventricle. Reported withdrawals across the mitral valve did not show a decisive diastolic gradient. Dye studies confirmed the shunt at the atrial level. The systemic blood flow was 5 liters/min. and the pulmonary blood flow was 17 liters/min.

From the above studies a diagnosis of atrial septal defect was made with certainty. An intracardiac phonocardiogram was done (Fig. 5), which revealed a mid-diastolic murmur in the inflow tract of the left ventricle. This sign has been shown [3, 7] to be diagnostic of mitral obstruction in the absence of increased flow through this valve.

On this sign alone a diagnosis of Lutembacher's syndrome was made, which was proven at operation.* In addition to an atrial septal defect, there was mitral stenosis. A valve orifice admitting only the tip of the surgeon's finger, was found.

Comment: The diagnosis of mitral stenosis associated with atrial septal defect presents considerable difficulties. Clinically it is not always easy to distinguish the

* Surgery was carried out in this case by Dr. W. G. Bigelow, Toronto General Hospital and University of Toronto.

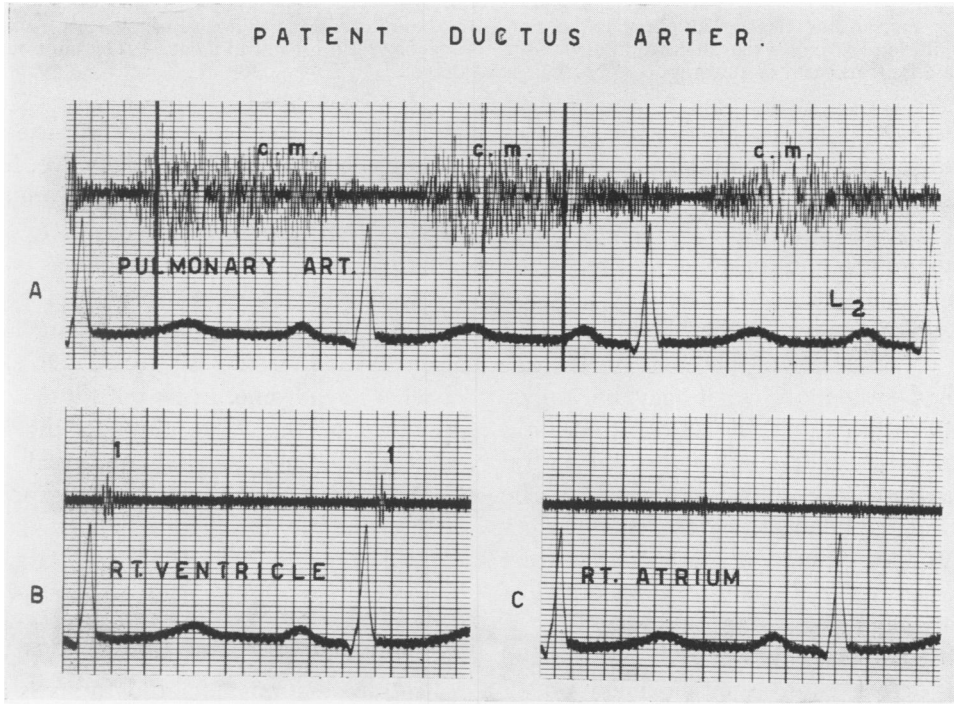

FIG. 4. A continuous murmur localized within the pulmonary artery is diagnostic of patent ductus arteriosus (when loudest at the bifurcation or within the left pulmonary artery) or aortic septal defect, (when loudest just above the pulmonary valves). In both these conditions no murmurs are recorded within the right ventricle and right atrium.

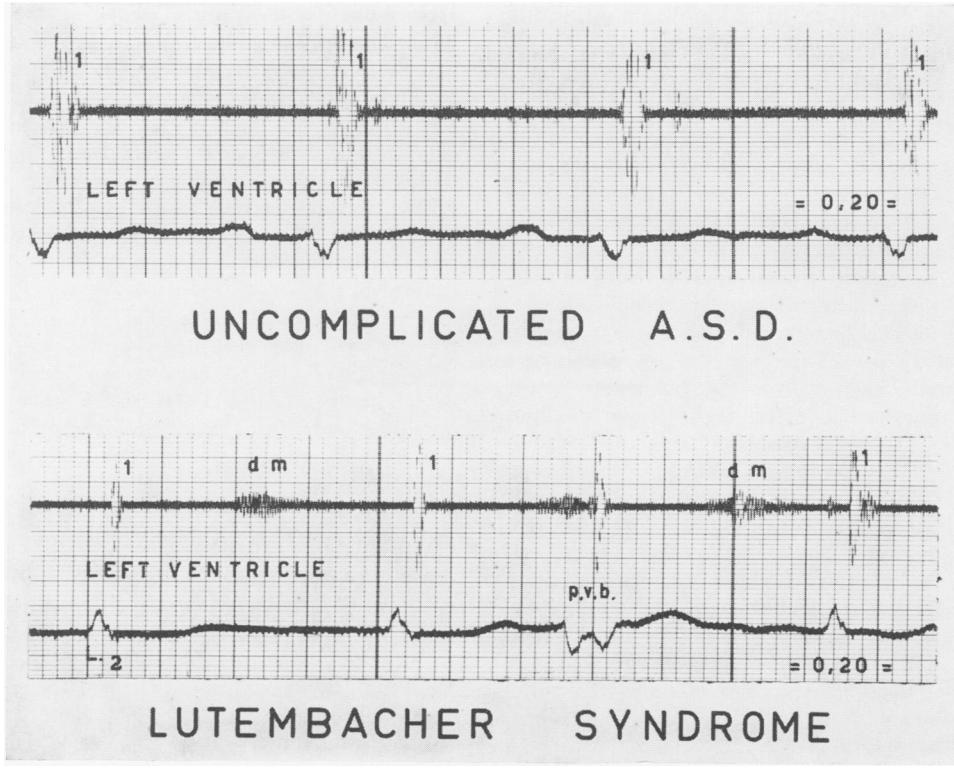

FIG. 5. The intracardiac phonocardiogram from the left ventricle in a case of Lutembacher's syndrome reveals a diastolic murmur which is a diagnostic sign of mitral stenosis. This murmur is absent in cases of uncomplicated atrial septal defect.

auscultatory features of mitral stenosis from those of atrial septal defect when they are associated. In both conditions a loud apical first sound, with an opening snap, and an apical mid-diastolic or presystolic murmur, may occur. Fluoroscopy and the ECG do not offer further help. At right heart catheterization, because of the diminished systemic flow, it may be impossible to define a diastolic gradient on withdrawal pressure tracings across the mitral valve, suggesting mitral obstruction. The intracardiac phonocardiogram, by revealing a diastolic murmur within the inflow tract of the left ventricle, is a useful method of certain diagnosis.

Mitral stenosis associated with atrial septal defect can be either acquired or congenital. In either case, particularly in congenital lesions, difficulty may be encountered by the surgeon in carrying out satisfactory commissurotomy because of the fibrous, leathery nature of the valve. Hence, cardiac bypass with operation under direct vision may be preferred to hypothermia and the well technic.

Among 60 cases of secundum type of atrial septal defect operated on in this center, there were six cases of Lutembacher's syndrome. In two of these a finger fracture of the valve through the septal defect was not possible and had to be abandoned. In the light of this experience a preoperative diagnosis of associated mitral stenosis and atrial septal defect is important.

Summary and Conclusions

Intracardiac phonocardiography is a simple and valuable technic, which is easy to perform and takes no more than 20 minutes. It provides precise localization of the

TABLE 1. *Localization of Intracardiac Murmurs of Diagnostic Value*

Heart Disease	Pulmonary Artery			Right Ventricle			Right Atrium		
	Systolic	Diastolic	Continuous	Systolic	Diastolic	Continuous	Systolic	Diastolic	Continuous
Normal Heart	+								
Ventricular Septal Defect	++			++++					
Pulmonary Stenosis	++++								
Patent Ductus Arteriosus			++++*						
Aortic Septal Defect			++++**						
Rupture of a Sinus of Valsalva into Rt. Vent.	++					++++			
Rupture of a Sinus of Valsalva into Rt. Atrium	++								++++
V.S.D. with Aortic Insufficiency	++			++++					
A-V Communis	++			++++			+++		
Atrial Septal Defect	++				(+)				
Lutembacher's Syndrome†	++				(+)				
Tricuspid Stenosis	+				++				
Tricuspid Insufficiency	+						+++		

* Loudest at the bifurcation or in the left pulmonary artery.

** Loudest in the main pulmonary artery just above the pulmonary valves.

† In Lutembacher's Syndrome a diastolic murmur, diagnostic of mitral stenosis, is recorded within the inflow tract of the left ventricle.

() Inconstant.

This table was derived from an experience of 200 cases studied with intracardiac phonocardiography [3] and from the experience of Lewis *et al.*, [10, 11] and Soulié *et al.*[15] Site and type of murmur is indicated at the top of each column. The number of + indicates the intensity.

A systolic murmur within the pulmonary artery is not specific. It is present in all normal subjects and increases in intensity in pulmonary stenosis or in cases of increased pulmonary blood flow. A murmur within the pulmonary artery is diagnostic of patent ductus arteriosus (when loudest at the bifurcation or in the left pulmonary artery), or of aortic septal defect (when loudest just above the pulmonary valves). Within the right ventricle: a systolic murmur is diagnostic of ventricular septal defect; a diastolic murmur indicates tricuspid stenosis; a continuous murmur is diagnostic of rupture of a sinus of Valsalva in that cavity. Within the right atrium: a systolic murmur indicates tricuspid insufficiency and a continuous murmur is diagnostic of rupture of a sinus of Valsalva in that cavity.

sources of cardiovascular murmurs; it is of diagnostic value in a few congenital or acquired heart diseases (Table 1) and is of considerable help in some complicated cardiac problems. Three problem cases, one of ventricular septal defect with pulmonary stenosis, one of ventricular septal defect with aortic insufficiency and one of atrial septal defect with mitral stenosis, are presented.

The usefulness of the intracardiac phonocardiogram in the diagnosis of ventricular septal defect when clinical and catheterization findings are equivocal, is emphasized.

The differential diagnosis in the presence of a continuous murmur with a wide pulse pressure and evidence of a left to right shunt, is clarified by intracardiac phonocardiography.

The difficulty in establishing the diagnosis of mitral stenosis associated with atrial septal defect may be solved by intracardiac phonocardiography.

Intracardiac phonocardiography is a further step in achieving a more accurate diagnosis in problem cases, by providing precise information as to the site and type of lesion. It has helped considerably in the decision for the surgical technic.

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